DEAN

A Review of the Problem Of the Electrification of the Saint Clair Tunnel on The Grand Trunk Railway

Railway Electrical Engineering

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A REVIEW OF THE PROBLEM OF THE ELECTRIFICATION OF THE SAINT CLAIR TUNNEL ON THE GRAND TRUNK RAILWAY

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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I N D E X

Page

A REVIEW OF THE PROBLEM OF THE ELECTRIFICATION OF THE ST. CLAIR TUNNEL.

INTRODUCTION.

It is the purpose of this thesis to compare the advantages of the various electrical systems with reference to their adaptability to the conditions in the St. Clair Tunnel, and to describe the equipment finally decided upon. With this end in view, it has been deemed advisable to discuss the problem under the following headings:

I. The Tunnel Prior to Electrification.

II. Need of New Equipment and Its Requirements

To Eliminate Danger Due to Smoke,

To Increace the Capacity of the Tunnel.

III. Different Electrical Systems Available,

Their Relative Costs and Efficiencies.

IV. Description of Electrical Equipment Chosen.

V. Construction and Operation of the New System.

Most of the technical information concerning conditions, requirements, apparatus installed and its operation have been taken from articles written by F. A. Sager, Assistant Engineer with Bion J. Arnold; and by H. L. Kirker, L. M. Aspinwell, and G. Bright, Engineers with the Westinghouse Companies. Bion J. Arnold is the Railway Company's consulting engineer, and West-

inghouse Companies are the general contractors.

The discussion of the electrical equipment to be chosen will involve a study of the inherent advantages and disadvantages of each system available, a comparison of the first costs of each, and, finally, an examination into their costs of operation. It will then be possible to judge which system, considering economy and excellence of operation, together with future conditions that may arise, should be used.

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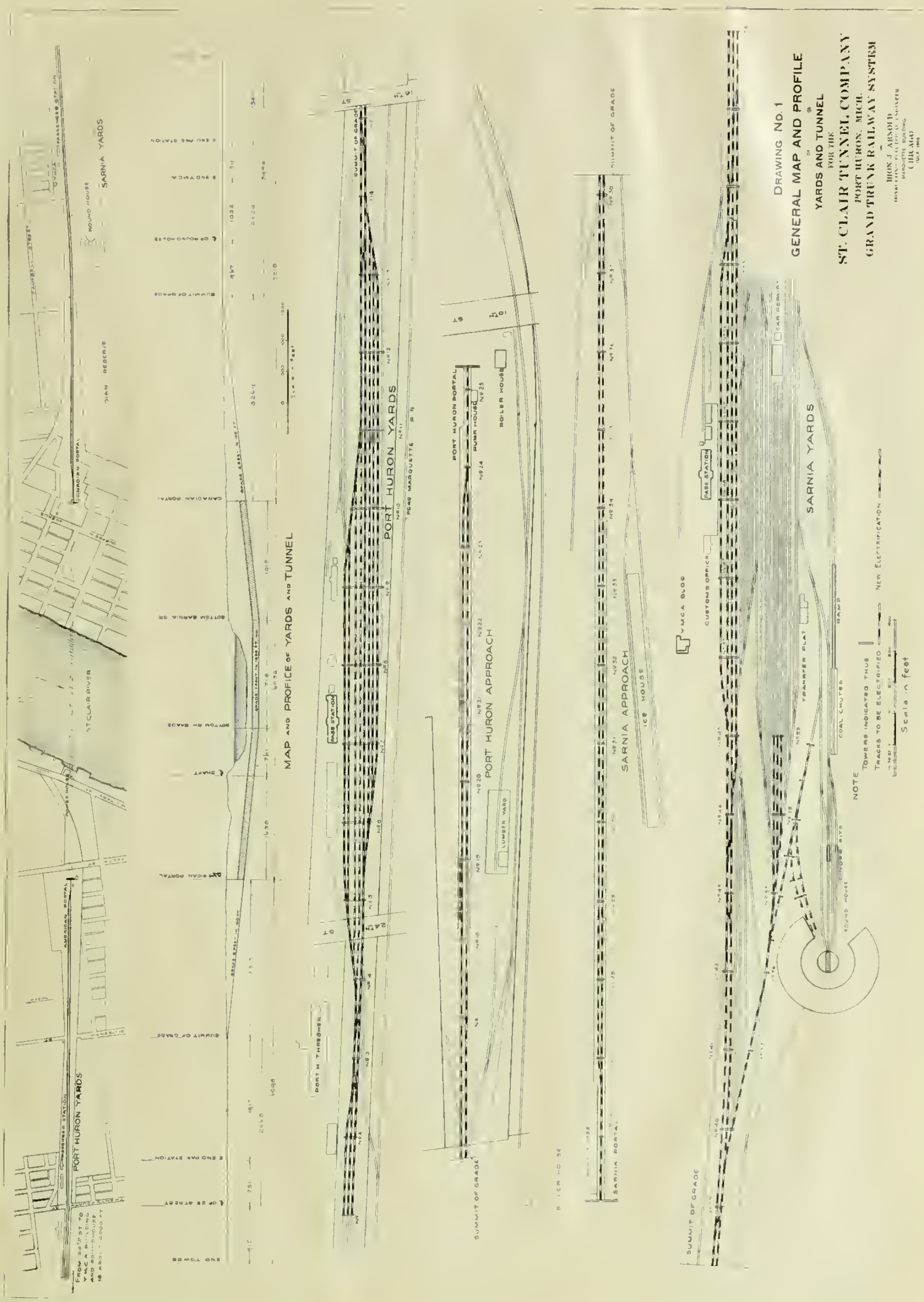

DRAWING No. 1
GENERAL MAP AND PROFILE
OF
YARDS AND TUNNEL
FOR THE
ST. CLAIR TUNNEL COMPANY
PORT HURON, MICH.
GRAND TRUNK RAILWAY SYSTEM
MAP AND PROFILE OF YARDS AND TUNNEL
PORT HURON YARDS
SARNIA YARDS
ST. CLAIR RIVER
PORT HURON APPROACH
SARNIA APPROACH
SUMMIT OF GRADE
CANADIAN PORTAL
AMERICAN PORTAL
PASS STATION
PUMP HOUSE
BOILER HOUSE
LUMBER YARD
ICE HOUSE
Y.M.C.A. BLDG
CUSTOMS OFFICE
TRANSFER FLAT
COAL CHUTES
ROUND HOUSE
PERE MARQUETTE R.R.
NOTE
TOWERS INDICATED THUS
TRACKS TO BE ELECTRIFIED
NEW ELECTRIFICATION
Scale in feet

I

THE TUNNEL PRIOR TO ELECTRIFICATION.

The St. Clair Tunnel runs under the St. Clair River, and connects the terminal of the Western Division of the Grand Trunk Railway System at Port Huron, Michigan with the terminal of the Eastern Division at Sarnia, Ontario. It was built by the St. Clair Tunnel Company, a subsidiary company to the Grand Trunk Railway System, in 1890, prior to which time the connecting link had been a car ferry.

The tunnel proper, which is constructed of cast iron rings 19 feet in diameter built up in sections, is 6,032 feet from portal to portal. The approach on the Port Huron side is 2,500 feet in length, and that on the Sarnia side is 3,300 feet in length, making the total length from summit to summit about 12,000 feet or two and one-fourth miles. As is shown by the profile of the tunnel on page 3 , the grade on the tunnel approaches and inclined sections is two per cent, with a 0.1 per cent down grade toward the east on the flat middle section, this latter being just sufficient to provide for the drainage of seepage water. Starting from the American summit, there is a down grade of two per cent for 4,914 feet, a down grade of one tenth per cent for 1718 feet, and an up grade of two per cent for 5,184 feet to the Canadian summit.

The drawing on page 3 shows also the lay out of the tracks in the yards at Port Huron and Sarnia and in the tunnel approaches. A double track is laid in the tunnel approaches, while, of

Sarnia Approach to Tunnel.

course, just a single track extends through the tunnel.

The tunnel approaches, having a total area of 24 acres, collect a great deal of water during a storm. Previous to electrification this water was taken care of by steam drainage pumps, necessitating the operation of a boiler plant at each end. Since it is of great importance to keep the tunnel dry at all times, the boiler plants required constant attendance, and steam was kept up a good part of the year.

From 1890 until 1908 the traffic of the tunnel was handled by four special locomotives. They were designed for the use of anthracite coal and, for steam locomotives, had an expecially high tractive effort.

Although these locomotives rendered a very good account of themselves, still the danger due to smoke and gases in the tunnel was considerable, and serious accidents were not infrequent. Electrification would remove the sinister reputation which these accidents gave the tunnel and remove the ever present discomfort to passengers while in it.

Air brakes could not be used in the tunnel, for, in case the train should break in two, it would be stalled, endangering the life of the crew until the locomotive could be uncoupled from the rest of the train.

The maximum tractive effort of the locomotives limited the weight of the trains to 760 tons, and even at such loads the speed was often excessively slow-- sometimes a great disadvantage.

II.

NEED OF NEW EQUIPMENT.

During seasons of heavy traffic, when lake shipping was closed, for instance, the capacity of the tunnel was often taxed to its limit, and this, as well as elimination of the danger due to smoke and gases and considerations of economy of operation, induced the Grand Trunk Railway to investigate various electrical equipments "to provide for the operation of trains thru the tunnel by means of electric locomotives; the handling of drainage and seepage water by means of electric pumps; the lighting of passenger stations, the tunnel, and the roundhouses by electricity, as well as furnishing a certain amount of power to the roundhouses"; and the supplying of a limited amount of outside lighting in the form of arc lamps.

In order to increase the capacity of the tunnel, it was necessary to provide for increased tractive effort in the new locomotives. With this in view, the electric locomotives were specified to be capable of developing a draw bar pull of 50,000 pounds when operating at a speed of ten miles per hour, 50,000 pounds being the maximum pull that would be safe in handling mixed rolling stock. The locomotives were further required to be able to haul a 1,000 ton train thru the tunnel, from terminal to terminal, in fifteen minutes, maximum speed in level track not to exceed twenty-five miles per hour and minimum up a two per cent grade not to be less than ten miles per hour. This would provide for a traffic capacity of 672 trains per week, each of

1,000 tons. For a typical week ending April 1, 1905, the traffic handled was 129,864 tons east bound divided into 208 trains and 76,743 tons west bound divided into 129 trains-- a total of 337 trains. Provided that this traffic could have been divided up into trains of 1,000 tons each, which would have been approximately possible, there would have been 206 trains. Thus electric locomotives such as specified would provide for fully three times the capacity actually required at the time under consideration.

The pump capacity, based upon previous experience, was specified as 5,500 gallons per minute at the Sarnia portal and 4,000 gallons at the Port Huron portal. Duplicate pumping equipments and duplicate feeder lines from the power house to the pump houses were required to insure perfect service.

It was estimated that the total lighting load would be not more than one hundred kilowatts and the power load another one hundred kilowatts.

Thus the new electrical equipment should provide for the intermittent locomotive load; the occasional pump load; and the power and lighting load, fairly constant during certain periods of the day.

III.

DIFFERENT ELECTRICAL SYSTEMS AVAILABLE-- THEIR RELATIVE COST AND EFFICIENCIES.

There are three systems that could be considered,-- direct current, single-phase, and three-phase. Any of these might or might not be used in conjunction with storage batteries to carry the peak of the load going up grade.

DIRECT CURRENT.

Direct current apparatus had been well tried and highly developed. The efficiency of direct current motors was good, the starting torque high, and, in the case of the St. Clair Tunnel, the line losses would not be excessive, since the length of the electrified zone would be less than four miles. If direct current were chosen, third rail instead of overhead suspension could be used, effecting a material saving in first cost. In case storage batteries should be used, direct current would have a further advantage in that the use of rotary converters between the alternating current side and the storage batteries would be obviated.

Direct current locomotives, however, have one disadvantage; they waste a great deal of energy in the resistances while starting and while running at any other than the full series or the full multiple positions. The conditions existing in the St. Clair Tunnel emphasized this disadvantage, for the runs were short and the speed variable: speed regulation was of "over-

whelming importance".

Another consideration that might argue against the adoption of direct current was the possibility of future electrification of adjacent sections of the Grand Trunk Railway system, in which case the alternating current system of distribution of power and the avoidance of rotary converter substations would be a decided advantage in favor of some alternating current system.

SINGLE-PHASE.

Although single-phase apparatus was still in the experimental stage, nevertheless single-phase locomotives larger than required had already been built; and, although the motors were not so efficient as direct current motors, yet the great variations of speed requirements could be better and more efficiently met with by means of the auto-transformer and the multiple switch control. In point of fact, the efficiency of the system as far as electrical energy is concerned might be as good as or better than that of a direct current system, and the electrical energy amounts to about one-half of the operating cost of locomotives per train mile.

The first cost of single-phase locomotives would be greater than direct current locomotives, but this difference would probably be offset by the difference in costs of the distributing systems.

Other points in favor of single-phase were that the electro-pneumatic, multiple unit control had been so perfected that alternating current motors could be better operated than direct current motors; and that single-phase practically eliminated all troubles due to electrolysis.

A disadvantage of single-phase in this particular instance would be that single-phase would not be suitable for the power load in the round houses or for the pump load. If three-phase generators were used and the single-phase power for the locomotives taken form one leg, the single-phase rating of the generators would be less than the three-phase rating of the same machines, and thus the first cost of the generators would be greater than would be the case if single-phase generators were used. Three-phase generators, however, had been more highly perfected than single-phase, and, as more were on the market, the difference in first cost might not be so marked after all.

THREE-PHASE.

A three-phase system would have all the advantages of distribution that single- phase would have and the attendent disadvantage of two and possibly three overhead conductors, depending upon whether or not the rails were used for one phase. The first cost of the additional overhead conductors and isulation joints required for three-phase would be considerable.

Three-phase induction motors are claimed to be very efficient and especially desirable for roads having steep grades, due to the fact that while going down grade power can be "pumped" back into the line by working the motors in concatenation. By this means also the motors act as a brake, eliminating wear on brake shoes. As a matter of fact, in the case of the St. Clair Tunnel, while one locomotive would be going down grade, comparatively little power would be consumed by another locomotive in the yards and other loads would ordinarily not amount to much more

than one hundred kilowatts, so that this power that could be returned to the line would find little use. It might be taken care of by storage batteries, but, assuming that this would pay, single-phase regenerative control could accomplish practically the same saving in power.

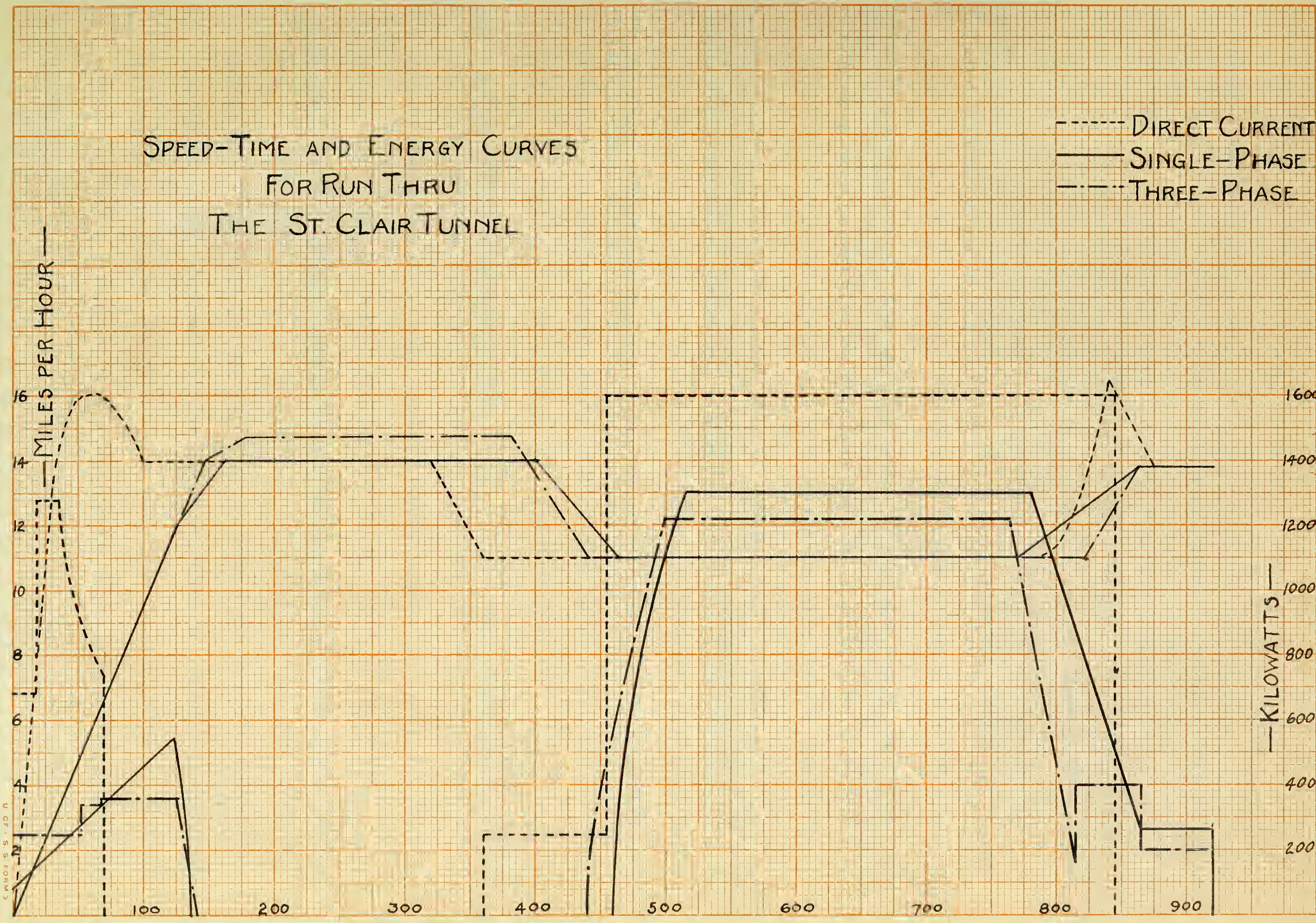
Furthermore, while the induction motor is very efficient, this is at two or three definite speeds, while flexibility of speed was specified as all important in this case, a characteristic that greatly favors single-phase.

The deciding element in this case, however, was the commercial availability of the apparatus. Three-phase equipment would have to be furnished by European manufacturers and actual bids from them showed that the cost of equipment would be greater for three-phase motors than for single-phase, although from technical considerations the reverse would seem probable. Besides, the desirability of having convenient access to a home manufacturer who would be responsible for the satisfactory operation of the equipment, and who would be able to deliver the equipment or return parts of it to the factory for any repairs without loss of time was almost so great as to preclude any possibility of installing three-phase.

FIRST COSTS OF EQUIPMENT.

The choice, therefore, lay between the direct current and the single-phase systems.

The first costs of these two systems differ in point of locomotive costs, distribution system costs, and costs of power house. Direct current locomotives for this installation would cost about $90,000. for three units as against $130,000. for single-


Speed-Time and Energy Curves
For Run Thru
The St. Clair Tunnel
Direct Current
Single-Phase
Three-Phase
Miles per Hour
Kilowatts
16
14
12
10
8
6
4
2
1600
1400
1200
1000
800
600
400
200
100
200
300
400
500
600
700
800
900
U. of I. S. S. Form 3

phase locomotives,-- about $40,000. in favor of direct current. The distribution system, including third rail return, could be assumed as about $6,500. a mile, or a total of $26,000. for direct current, while single-phase, requiring only a trolley conductor delivering current at 3,300 volts, could safely be assumed as $5,000. a mile, a total of $20,000. As shown by the energy time curves, for a 1000-ton train the maximum kilowatts required would be 1,600 kilowatts for direct current and 1,300 for alternating current. The maximum load on the plant using single-phase would be about 1,300 kilowatts for a locomotive on the grade, plus 500 kilowatts for a locomotive handling a train in the yards, plus 700 kilowatts for pump, lighting, and power load-- 2,500 kilowatts. Assuming 2,500 kilowatts as the capacity of the power house using alternating current and ten per cent more, or 2,750 kilowatts, as the capacity of a direct current power house, the single-phase power house would cost $250,000. at $100. per kilowatts and the D. C. power house $275,000.

Thus the cost of locomotives is $40,000. in favor of direct current, the cost of distribution systems $6,000. in favor of alternating current, the cost of power house $25,000. in favor of alternating current, making the total cost of equipment $9,000. out of about $500,000. cheaper for direct current. This is comparatively a very small difference, and the figures given are only estimates, so that it would be safe to consider the first costs for the two systems equal. If, however, storage batteries should be decided upon, the additional cost of rotary converts would increase the first cost of single-phase equipment.

COSTS OF OPERATION.

The cost of electrical energy amounts to one-half of the cost of operation. The other half-- labor, up keep of track and equipment-- would be practically the same for either direct current or single-phase, so that any difference in costs of operation must be decided by difference in costs of power consumed; and, since the power consumed by pumps, lights, and round house motors can be considered as the same for each system, the difference would occur only in the locomotive runs.

From the energy curves shown on page 13, a direct current locomotive with a 1000-ton train would require about 155 kilowatt-hours as against 140 kilowatt-hours for a similar run with a single-phase locomotive. Assuming an average of 206 runs per week, this would mean a saving of about 161,000 kilowatt-hours per year. If it cost 1 cent to generate kilowatt-hours, the annual saving would be \$1,610., equivalent to an investment of \$32,000. at 5 per cent or three-tenths per cent on the actual investment.

It has been shown, then, that single-phase locomotives surpass other locomotives in flexibility of speed control; that the first costs of equipments for single-phase and direct current systems would be practically the same, three-phase being put out of consideration on account of inaccessability of manufacturers; and that the cost of operation would be about three-tenths per cent of the original investment in favor of single-phase. This, in addition to the consideration of possible future electrification of adjacent sections of the trunk line, argued decisively in favor of single-phase.

IV.

DESCRIPTION OF SINGLE PHASE EQUIPMENT DECIDED UPON.

LOCOMOTIVES.

Three locomotives, each consisting of two separate half-units, were designed to meet conditions found in handling both freight and passenger trains thru the tunnel.

Each half-unit has three pairs of drivers driven thru gears by three 250 horse power single-phase motors, so that a complete unit, such as would be used in hauling a 1000-ton freight train, can develop 1,500 horse power normally and 2,000 horse power when occasion demands. A complete locomotive weighs 132 tons, and a test showed that it can develop a draw bar pull of 86,000 pounds before slipping the wheels. It requires but 50,000 pounds draw bar pull to haul a 1000-ton train up a two per cent grade at about eleven miles per hour. The maximum speed of the locomotives on level track is thirty-five miles per hour, although it is not intended to run them in excess of thirty miles per hour, at which speed the draw bar pull will be 6,000 pounds. A speed indicator in the locomotive cab assists the engineer in keeping the speed of the train within the prescribed limits, and a speed recorder furnishes records of the speed of the trains thruout all trips for the inspection of the tunnel superintendent.

The diameter of driving wheels is 62 inches. They are built up with cast iron centers and steel tires secured in place by double "MANSELL" retaining rings. The total weight of the locomotive rests on the drivers.

The motors are of the ten-pole compensated type, operating at

Complete Unit

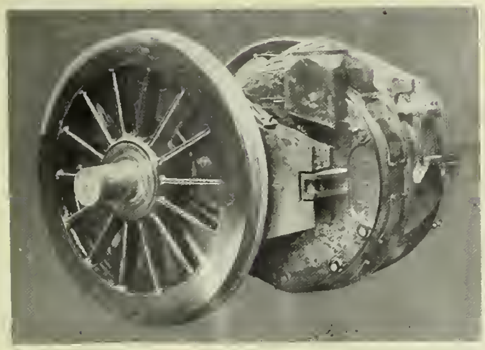
a normal voltage of 235 volts at 25 cycles. They are connected only in multiple and are so arranged that any motor may be disconnected, in case of trouble, by cut-out switches mounted on the end of the reverse group. By the use of forced ventilation the continuous capacity of a locomotive is 750 amperes at 235 volts, which would allow it to pull a 2,500-ton train at a constant speed of fifteen and one-half miles per hour on a straight level track for any desired length of time.

The locomotive frames "are of the rigid outside bar type, and consist esentially of two cast steel side frames joined at the ends by heavy cast steel bumper girders and reinforced by cross braces at two intermediate points. The main journal boxes are carried in the side frames in recesses fitted with gibb and wedges."

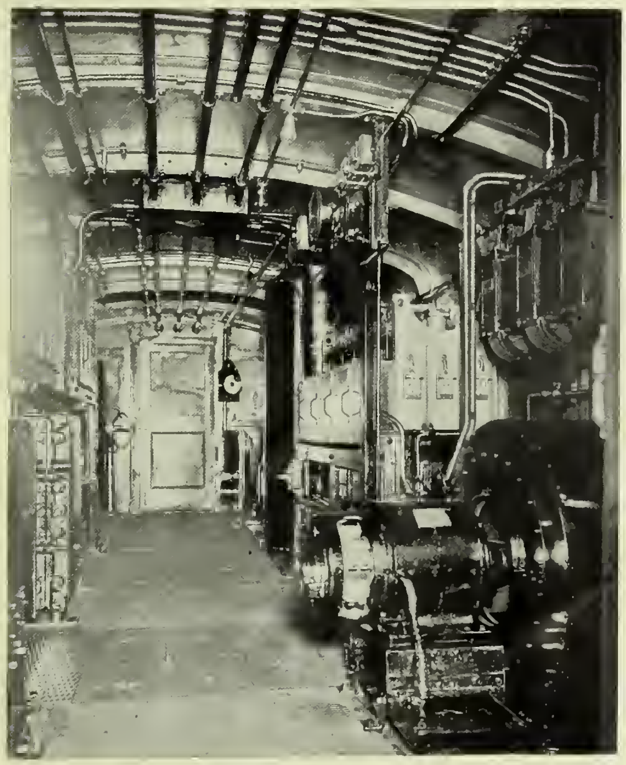
The cab is rectangular in section, constructed of sheet metal with a Z-bar frame built upon an angle iron base frame. There is a wide aisle down the middle of the cab, and the auxiliary apparatus is arranged on each side of the aisle. Trap doors in the floor make the motors easy of access. In order that the locomotive can be operated from either end, there is a master controller, ammeter, and set of air brake valves at each end of the cab. As shown in page , all apparatus in the cab is arranged so that it can be readily inspected and replaced.

THE CONTROL SYSTEM AND AUXILIARIES.

The speed of the locomotive is regulated by varing the vollage at the motor terminals. This is accomplished by a multiple switch system with air operated, electrically controlled switches. The



Motor and Driving Wheels



Interior of Locomotive

controller has twenty-one points brought from taps on the auto-transformer, providing for seventeen running and three switching points—normally, four points are closed by the contactor switches. The diagram on page 21 illustrates the layout of the multiple switch control system. By thus providing for an increase in speed of the locomotive from the lowest running speed to the maximum with very slight gradations, it is possible to maintain a practically constant draw bar pull while the locomotive is accelerating the train. Keeping the draw bar pull practically constant while hauling the train thru the tunnel decreases the liability of breaking the train in two, for which reason special attention was given this phase of train operation in designing the locomotive.

The CONTROL SYSTEM AND AUXILIARIES comprise a 3,300 volt auto-transformer, three preventive coils, three switch groups, a train line relay, two master controllers, two small storage batteries, a small motor-generator set, an air compressor and a blower. The auto-transformer is shown in the picture on page on the right hand side of the cab in the center. It is connected to the trolley by a high-tension cable thru an oil circuit breaker with a no-voltage release protective relay. Should the locomotive leave the rails and thus become insulated from them, this relay would cause the circuit breaker to open and remain open until the ground connection to the locomotive had been re-established.

Three preventive coils located directly over the blower provide a means of stepping from one transformer tap to another

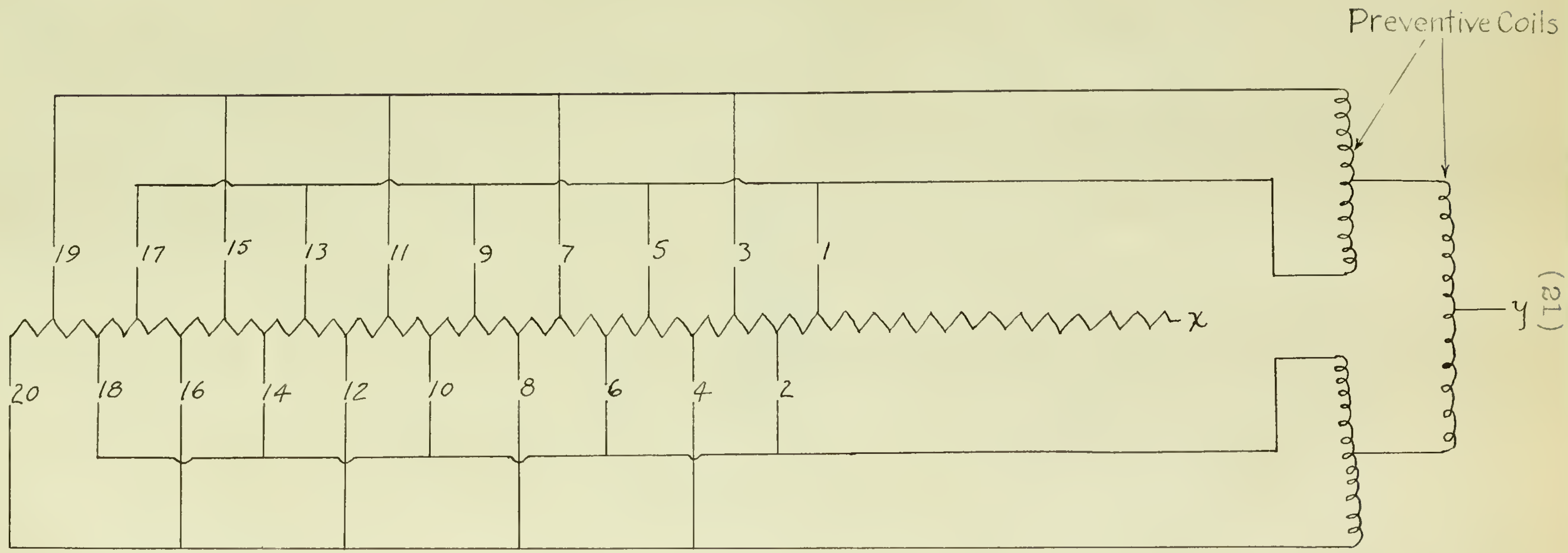


Diagram of Multiple-Switch Control.

without producing a short-circuit in the transformer or an open circuit to the motors. They also serve to distribute the motor current among the four switches in the transformer switch groups.

There are three switch groups,-- two transformer switch groups and one reverser switch group, all electro-pneumatically operated. The former are located above the transformer with the train line relay between them, so that the leads between the switch groups and the transformer are very short. The reverser switch group is located on the left side of the cab as shown on page and consists of twelve switches. Four of these are for each motor-- two for operation in the forward direction and two for reversing.

The train line relay between the two transformer switch groups enables a number of the wires leading from the master controllers to be used twice, thus cutting down the number of control wires required between half-units when operating in pairs, and also shortening the length of the controller drum.

A master controller is located at each end of the cab on the right hand side, so placed that the engineer can have a clear view from his seat while operating the controller and brake valves. On each master controller there are two interlocking handles, one the operating handle and the other the reversing handle. The master controller operates the switches by means of current from a storage battery and has seventeen running notches and three switching notches. Since there is no resistance in the motor circuits to overheat and burn out, these locomotives have, as has been explained before, a very distinct advantage over the direct-current type, where only two or three running notches are

available. The switching notches (corresponding to points 1,2,3 in diagram on page 21) are used only when the locomotive is passing over switches and frogs in the yards, running at slow speeds and without loads.

Ten cell (20 volts) storage batteries used in operating the control magnets are in duplicate, so that one may be in use while the other is being charged. The charging is done by a 100 watt motor-generator set.

The air compressor is located on the left side of the cab. The maximum pressure of 100 pounds gauge is lowered by a reducing valve to eighty pounds for use in the control system.

The blower, which is located on the right side, is driven by a single-phase motor, the current being taken at 100 volts from a tap on the main transformer. It takes air thru a shutter in the side of the locomotive and distributes is thru sheet metal ducts under the cab floor to the three motors and to the transformer. From the latter the air may pass either out into the open air, or, in cold weather , into the cab.

In addition to the above equipment, each cab has sand boxes; seats for the motorman; ammeters; voltmeters; wattmeters; circuit breakers (set to open at 4,500 amperes); and push buttons for operating the pneumatic bell ringer, pneumatic sanders, the circuit breaker reset, and the pantagraph trolley. There are also foot pedals which may be used to operate the bell and sanders.

BRAKE EQUIPMENT.

The brake equipment is of the standard double ended type with an automatic and independent air brake valve at each end of the

cab. In addition to this a hand brake is installed on each half-unit.

CURRENT COLLECTOR.

The current is collected from the trolley wires by a pantagraph trolley of standard form. To raise the trolley and hold it against the wire springs are used, while compressed air is used to lower it and operate the locking mechanism.

The following are the general dimensions of the half-units:

Length over all----------------------------23 feet 6 inches.

Height from top of rail to top of roof----13 feet.

" " " " " " " " panta-
graph bow when lowered--------------------14 feet 11 inches

Height from top of rail to top of panta-
graph bow when raised---------------------22 feet.

Width of cab over all-------------------- 9 feet 8 inches

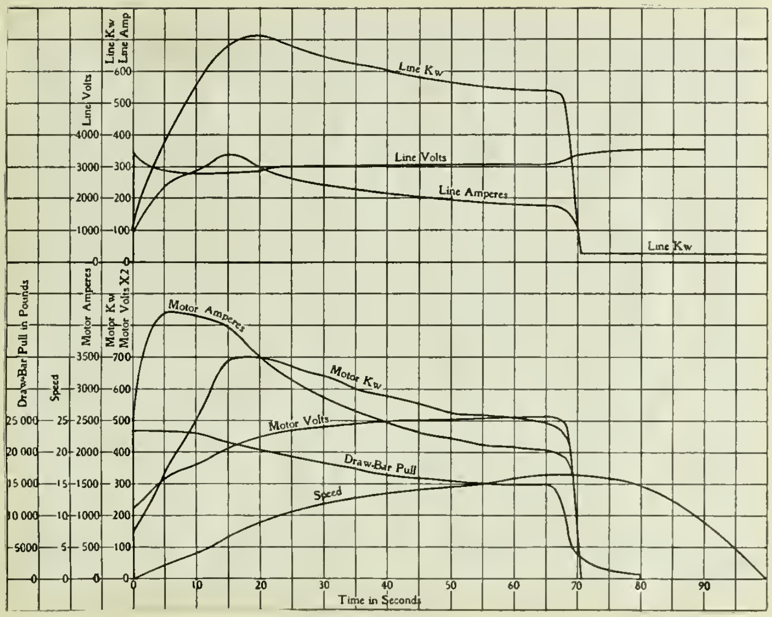
Total weight of locomotive half unit fully
equipped----------------------------------67 1/2 tons.

Length of rigid wheel base----------------16 feet.

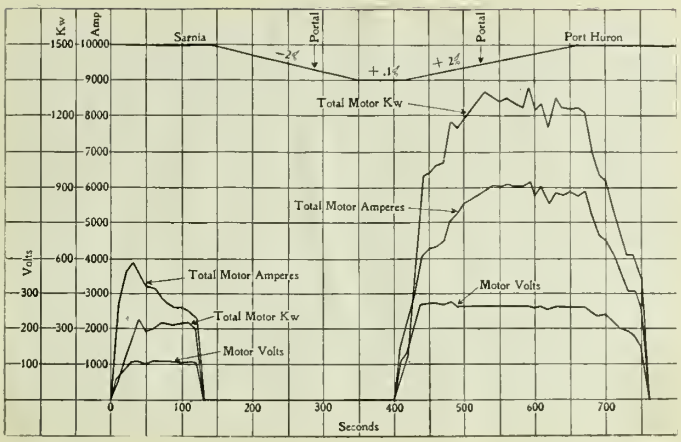
Diameter of driving wheels----------------62 inches.

Two half-units are generally required in hauling freight trains thru the tunnel, while a passenger train can usually be handled by a single half-unit. It is found that the locomotives can handle a 1,000-ton train at from eleven to fourteen miles per hour on a two per cent grade, which is more then fulfilling their specified performance.

The curves on page 25 show the results of a test on a half-unit on the interworks railway of the Westinghouse Company. The



Curves Showing Results of Tests on Half-Unit on Interworks Railway.



Curves Showing Results of Tests on
Complete-Unit Run Through
The St. Clair Tunnel.

curves on page 26 show the results of a test on a complete locomotive on a run thru the St. Clair Tunnel.

PUMPING.

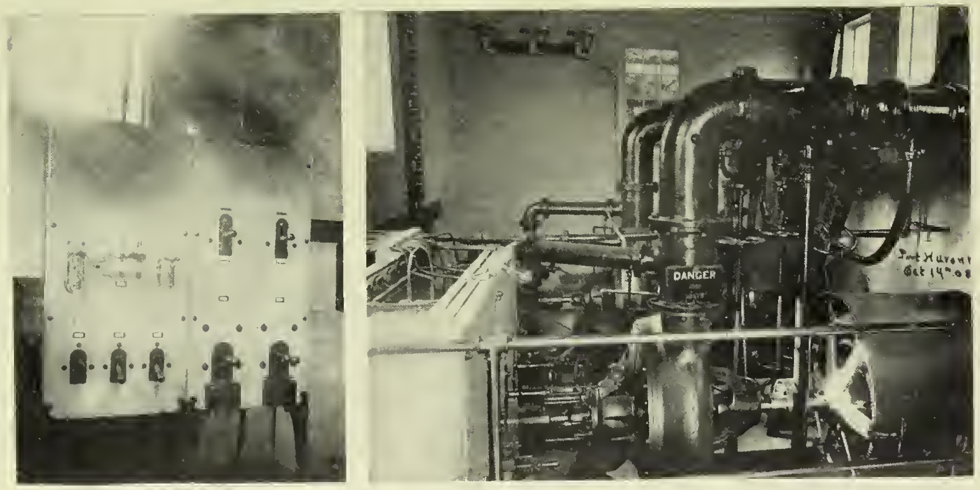
The pumping plants were designed to free the tunnel approaches from water due to rain storms and melting snow as well as to dispose of condensation and seepage water in the tunnel. Since there are thirteen acres of the Canadian approach to drain and only eleven acres of the American approach, the pump house at the Sarnia portal is equipped with two centrifugal pumps of 5500 gallons per minute capacity each, direct connected to 200 h. p., 3-phase, 25-cycle, 3,300 volts, induction motors; while that at the Port Huron entrance has two 4,000 gallon pumps and two 100 horse power motors of the same type. Each pump house is also provided with a 150 gallon induction motor driven pump to take care of ordinary drainage water that is constantly finding its way into the drainage wells.

To take care of the tunnel seepage, there are two 100 gallon centrifugal pumps at the foot of the Canadian grade, which discharge into the well at the Canadian entrance. The induction motors operating these two pumps are 440 volts, entirely enveloped and usually run but six hours per day each.

The drainage equipment has been found to operate in a manner entirely satisfactory, and handles the water with a minimum of attendance and expense.

LIGHTING AND POWER.

By means of 3,300-one hundred ten volt transformers the power house supplies light to the round houses, the passenger stations,



Interior of Pumping Station.

and the Young Men's Christian Association building in both Port Huron and Sarnia.

In the tunnel there are 480 lights operated four in series from 440-volt transformers. These lights are placed in two rows on either side of the tunnel, spaced every twenty-five feet and staggered.

A mercury arc rectifier furnishes current for about thirty arc lights installed in the yards at either terminal.

This makes a total amount of about 100 kilowatts for lighting, which, together with 100 kilowatts for 3,300 volt motors in the round houses, requires about 200 kilowatts as a maximum for small power and lighting outside of the power house.

DISTRIBUTING SYSTEM.

Seventy-five feet from the power plant there is a vertical shaft extending down to the tunnel. All feeders from the power house pass down a reenforced concrete duct in the shaft thru holes in the tunnel shell. At this point (1,700 feet from the Port Huron portal) the locomotive feeders tap the trolley and rail, the only distributing point for the whole trolley system. There are section breaks and switches which may be used for isolating particular sections in case of accidents. The other feeders are carried thru the tunnel in ducts to the pump houses.

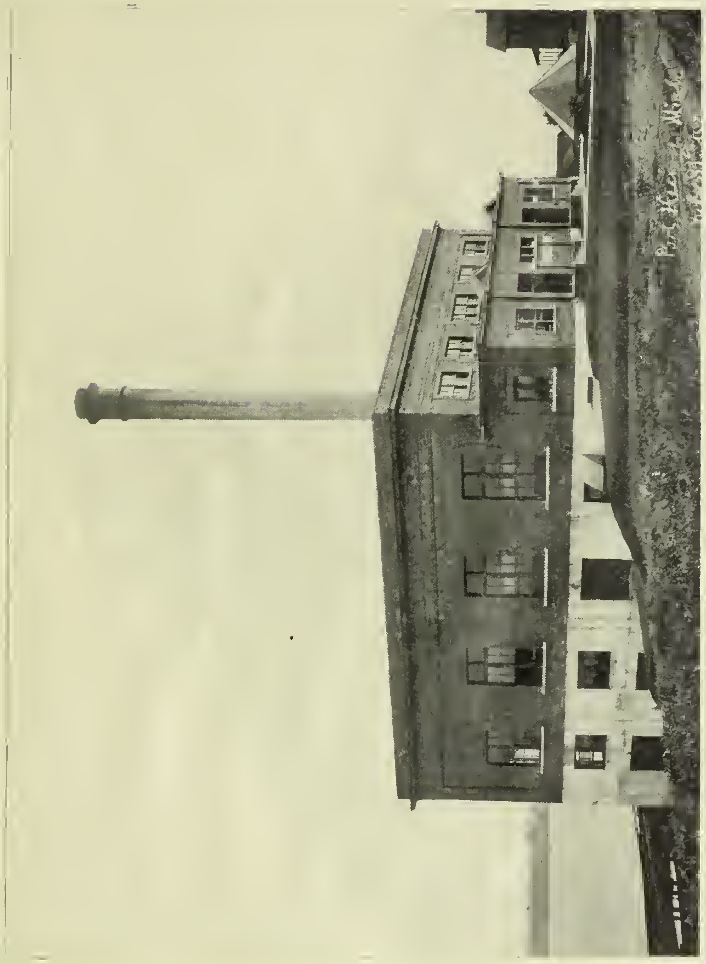
For distribution of the single-phase current to the locomotives the tunnel is equipped with two parallel 300,000 circular mil grooved copper conductors and two parallel steel messenger cables. The messenger wires are supported from the tunnel shell every twelve feet on barrel type insulators, and the trolley wires are supported from the messenger wires by hangers also located

Overhead Work at Port Huron Station.

every twelve feet, but three feet from the middle of messenger spans. There is a clearance of three inches between the messenger cables and tunnel shell, while the trolley wires are six inches below that, giving a maximum clearance of fifteen feet, five inches between trolley wires and rails.

In the tunnel approaches and yards the ordinary catenary trolley construction is used. A 5/8 inch galvanized steel messenger wire is suspended every 250 feet on the insulators located on overhead bridges. Number 4/0 hard-drawn groved copper is supported from this at a uniform height of twenty-two feet above the rails. The overhead bridges are of a trussed construction supported by strong lattice columns. They are designed to span all tracks that are electrified as well as the platforms at the passenger stations. Some of the bridges spanning seven electrified tracks and the platform at the Port Huron station have a length of 143 feet. By tying them together with guy cables, a lighter construction was permissable than would have been had each bridge been designed to withstand the stress resulting from the breaking of messenger cables and trolley wires.

In the tunnel ducts running from the power house shaft to either pump house are two feeders for tunnel lights, two for each pump house group, a three-phase power feeder, and an arc light feeder for the yards at either end terminal. These feeders are paper insulated, lead covered cables and terminate at the pump house switch boards. From this point the arc light circuit and three-phase power circuit continue as bare overhead wires, carried on the columns at one end of the transmission bridges, which have been lengthened for that purpose.



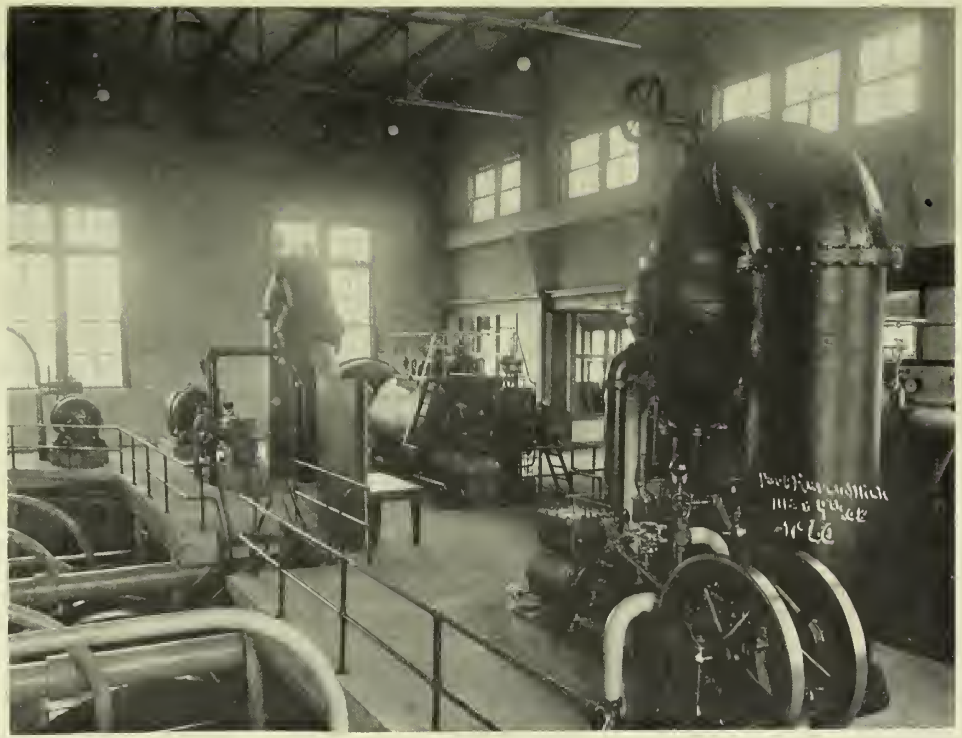
Power Plant

POWER PLANT.

The power plant is located on the Port Huron bank of the St. Clair River, almost directly above the tunnel. It is built of concrete up to the dynamo room floor, above which point a self-supporting steel structure is lined with paving brick and corniced and cooped with concrete. The roof is of cinder concrete. The walls of the dynamo room are lined with enamel brick as high as the top of the switchboard and from there on with sand lime brick. The dynamo room basement contains condenser pumps and stoker fans and is so recessed that the apparatus may be seen from the dynamo room. The boiler room is on a level with the basement of the dynamo room. It has a reenforced concrete coal bunker having a capacity of 500 tons. The offices and switchboard room are in front of the dynamo room and face the street.

In the dynamo room there are two 1250 kilowatt, three-phase, 25 cycle, 3300 volt Westinghouse Parsons turbo-generators, either of which is ordinarily capable of handling the load. These generators, which could be rated as 1500 kilowatt machines if only three-phase power were used, furnish the locomotives and incandescent lights with single-phase current, and the power house motors, drainage pump motors, and round house motors with three-phase current. The auxiliary apparatus on the dynamo room floor consists of an independent barometric jet condenser for each turbine, two steam driven exciters, a motor driven exciter group, and a TIRRILL regulator for keeping the voltage of the locomotive phase constant over the entire range of load.

The load is an extremely variable one, since there can be but



Turbine Room.

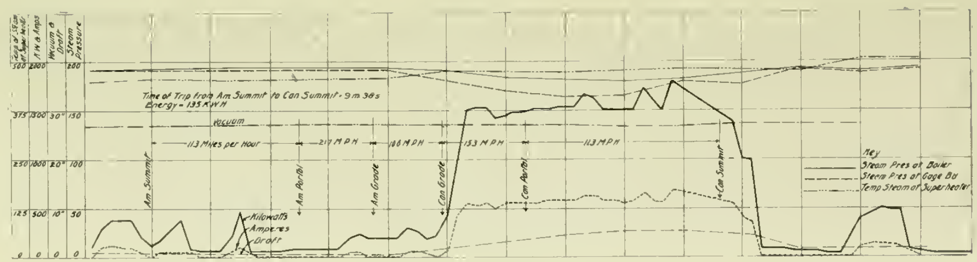
one train on a tunnel grade at a time, and on this account the turbines have a large overload capacity and the boilers on extra large steam drum capacity. There are four 400 horse power boilers, of which three are ordinarily in use, although two can take care of the average load. Whenever a heavy load comes on, causing the boiler pressure to drop, the speed of the forced draft fan automatically increases as well as the fuel supply to the underfeed stokers. The superheater has a large heat storage capacity. The temperature is automatically controlled so as to give a low, uniform superheat. Only the turbines use superheated steam; the auxiliaries use low pressure saturated steam and exhaust into the feed water heater.

V.

CONSTRUCTION AND OPERATION OF THE NEW SYSTEM.

The construction of the power plant in no way interfered with the operation of the railroad, and the overhead construction in the yards did not interfere to any serious extent; but how to install the tunnel equipment without tying up the system or deflecting the traffic to the Detroit ferries was a problem. Although bonding, building of tunnel duct lines, and putting in place the tunnel insulators could be done a little at a time, stringing continuous wires from portal to portal would require a couple of days in succession. To get around this, the wires were cut and run in from each portal, being spliced in the middle. It required only four periods between 1 A. M. and 4 A. M. to tie up all the wires temporarily. This was accomplished by placing the reels on a flat car, letting it down grade with the brakes, and following it up with a box car, on top of which were the men who tied up the wires. The remainder of the work could be done without much trouble.

After the installation had been completed, it still remained to school the employees in the operation of the new equipment. Each one of them was required to pass a written examination, after which occasional test runs were made thru the tunnels with the locomotive running light. Later, light trains were hauled thru as test loads, and finally the electric locomotives were allowed to handle a limited number of regular trains. In this manner the employees gradually became familiar with the new equipment, and the transition from steam to electricity was made easy.



Graphical Log of Power House Operation; Condensing.

(Weight of Train with Locomotive, 1020·5 Tons)

Since the new equipment has been put in operation, May 17, 1908. there have been no serious failures and few that are worth mentioning at all. Once the trolley wire in the tunnel was burnt in two because carless resetting of the pantagraph by the crew of a work train caused it to knock the wire against the tunnel shell. Lightning arrester failures occasioned by birds have caused momentary interruptions, and twice loss of vacuum in the condensers have caused momentary power house failures.

On page 37 is shown a typical load curve. It shows the variation in power required by the locomotives, variation in boiler pressure, forced draft pressure, superheat during the passage of a train from one terminal to the other. The efficiencies of the various parts of the equipment separately and as a whole are up to contract specifications, and the operation up to the present time shows that the economies effected by electrification are slightly greater than those estimated.

The electric locomotives have proved to be less severe on the rails than steam locomotives; the depreciation of the passenger coaches, due to the action of steam and hot gases while in the tunnel, has been eliminated; and the coal bill has been greatly reduced. The record these locomotives have already made, handling as they do the heaviest railway service operated by electricity in the world, up holds the engineer's decision in favor of single-phase locomotives.